What's the Matter?

Suggested Grade Level(s): 7 - 12
Estimated class time: two 50-minute class periods, plus extra time for lesson extensions. In addition, allow one class period for reading *Cosmic Times* if they have not yet read the article relating to dark matter, "Galaxies Still Misbehaving"

Summary

Students will explore the density of substances as a model for understanding the mass to light ratio as a predictor of dark matter. Students will try to explain a discrepant event when data is not as expected.

Objectives

1. Students will measure and calculate mass and volume to calculate the density of a foam ball.
2. Students will try to explain a discrepant event when presented with a nerf ball that seems too heavy for its volume.
3. Students will use the concept of density, a ratio of mass to volume, to attempt to explain the mass to light ratio for luminosity and gravity.

National Standards

NS.9-12.1 **SCIENCE AS INQUIRY**

As a result of activities in grades 9-12, all students should develop

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

NS.9-12.2 **PHYSICAL SCIENCE**

As a result of their activities in grades 9-12, all students should develop an understanding of

- Structure of atoms
- Structure and properties of matter

Knowledge Prerequisite

- Students will need the formula for the volume of a sphere and circumference of a circle.
- Students need to be able to do simple algebra.
- Students need to be familiar with density as a property of matter and how to calculate it with a formula.

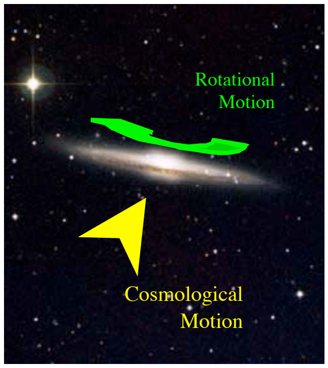
Teacher Background/Notes

The following is information to supplement the article "Galaxies Still Misbehaving."

"Galaxies Still Misbehaving" introduces the idea of "unseen" material in the Universe. Not only is matter unseen in the galaxies, but also in galaxy clusters.

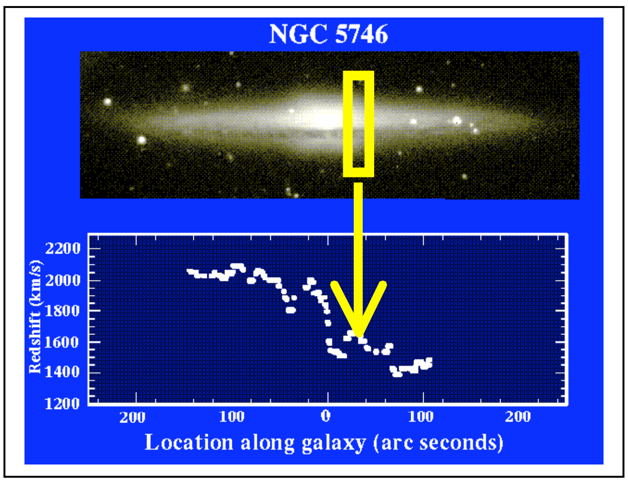
Methodology for relating redshift, luminosity and mass in a galaxy.

1. Galaxies can exhibit two redshifts
   a. Cosmological due to the expansion of the Universe
   b. Rotational due to the motion of the galaxy itself.



2. Find the redshift of a "slice" of the galaxy.

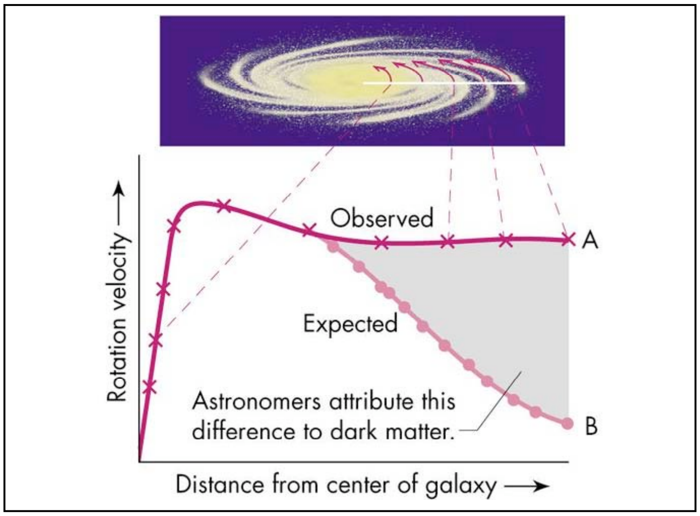
3. This gives the combined (rotational plus cosmological) redshift of that slice (below)



4. Repeat for many different slices of the galaxy

5. The resulting plot of redshift versus distance from the center of the galaxy is called a rotation curve

6. The resulting rotation curve can be compared to that expected if all of the mass were visible as luminous matter (below).



7. The rotation curve can also be used to measure the amount of mass in the galaxy needed to produce the observed rotation (see derivation at end of the section).

8. Scientists then compare the brightness of a galaxy to our sun using the predicted mass. Then they get a mass-to-light ratio, using the measured luminosity and comparing it to our sun.
   a. If mass-to-light ratio =1, all the mass is represented in the luminous matter.
   b. Instead, if the mass-to-light ratio is > 1, this indicates that there is more mass than the luminous matter

9. Scientists try to explain the missing matter.

Gravitation and Speed relationship for step 7 above.

The 1919 *Cosmic Times* highlighted the triumph of Einstein's Model of Gravity over Newtonian Physics. Nevertheless, we can still use Newton's Theory of Gravity to make valid predictions in the Universe. This is one such example.

Newton's Law of Universal Gravitation relates the force pulling on a mass (m) to the mass of the object doing the pulling (M) and the distance between them (r). There is a Universal Constant G in the formula as well. It is more complicated with a galaxy full of matter instead of two discrete simple spheres, but the idea is the same.

$$F_G = G\frac{mM}{r^2}$$

This force is a centripetal force and can be equated to:

$$F_C = \frac{mv^2}{r}$$

Now set gravitational force equal to centripetal force:

$$F_C = F_G$$
$$\frac{mv^2}{r} = G\frac{mM}{r^2}$$

Cancel the mass of the object being pulled:
$$\frac{v^2}{r} = G\frac{M}{r^2}$$

Solve for the mass since we know the speed and distances from the redshift information:

$$\frac{r^2v^2}{rG} = M \text{ or } M = \frac{rv^2}{G}$$

The data from the rotation curve predicts the Mass in a galaxy and does NOT agree with luminosity measurements.

Materials

- A few blocks of wood – identical except for the size.
- A small foam ball for each group.
- A tape measure or piece of string (one per group) to wrap around the foam balls.
- A triple beam balance for each group.
- One or more "loaded" foam or Styrofoam balls – see "Preparation" section below.
- Posterboard, whiteboards, or large sheets of construction paper and appropriate markers.

Preparation:

Prior to teaching this lesson, the teacher needs to prepare a loaded foam or Styrofoam ball as a discrepant event.

- Using a sharp knife, cut a slit in the foam ball. This should extend into the center of the ball. It is even possible to pull out some of the center foam to make a cavity in the center of the ball.
- Put some weights into the center of the foam ball. These can be hooked or slotted masses, some metal washers, stones, etc. There needs to be enough extra weight so that the different in mass is obvious. They should fit snugly and not rattle around. They should fit in such a way that the slit in the ball closes naturally and is not immediately obvious to the students.

Procedure:

I. Engagement

Day 1

Scenario:

Have the students imagine that they are astrophysicists working for NASA in 1965 and the measurements they are taking do not make any sense. When they measure the redshifts of stars as a function of their distance from the center of galaxies, the stars are moving too fast compared to the amount of light that they see. There just isn't enough matter in the galaxies to produce the observed results.

The students/astrophysicists must report on their findings and hypothesize what might be causing the higher speeds and what the "missing" matter might be. They will write a one page report to your superiors detailing what their research has found and what the extra matter might be.

II. Exploration

Part 1

Set:
Show two wooden blocks to the class.
Explain that the only difference is that one is bigger than the other.
Ask students to make a prediction that compares the mass of the two blocks.

- ★ The larger block should have the larger mass.
- ★ <u>Think – pair – share</u> the answers:
    - o Students will think to themselves what they predict.
    - o Students will share their thoughts with a partner.
    - o Students will be invited to share their predictions with the whole class.
    - o Ask students if there are other ideas after one student has shared.

Pass the blocks around so students can verify their predictions by holding the blocks in both hands OR ask students to find the mass of the blocks on a triple beam balance.

Determining the density of the foam balls.

`Students will predict the mass of a large foam ball by first calculating the density of smaller foam balls.`

Give each group of students a foam ball, a tape measure or piece of sting and meter stick/ruler, and a triple beam balance.

1. Students will wrap the tape or string around the outside of the foam ball and measure the circumference of the ball in centimeters
    - If they are using the string, they will mark the length on the string and lay it on the meter stick to determine the distance around the ball.

2. Students will calculate the radius of the sphere from the circumference using the formula:

    $circumference = 2\pi \times r$, where r is the radius in centimeters

    algebraic manipulation yields:

    $$r = \frac{circumference}{2\pi}$$

3. Students will calculate the volume of the sphere in centimeters cubed.

    $$Volume = \frac{4}{3}\pi \times r^3$$

4. Students will use the triple beam balance to measure the mass of the ball in grams.

5. Students will calculate density in grams per cubic centimeter using the formula:

    $$density = \frac{mass}{volume}$$

6. Students should record their density values in a chart on the board. Allow students to troubleshoot any obvious errors.

7. Calculate the average of the individual values.

Part 2
Calculate the density of the loaded foam ball.

8. The teacher will measure the circumference of the loaded foam ball.

9. Students will then repeat steps 2 and 3 for the loaded large ball.

10. Students should use the calculated volume of the loaded ball and predict the mass of the ball. Use the average density from the student data in part 1 step 7.

    $mass = density \times volume$

11. Place the ball on a triple beam balance and invite one student read the mass of the ball.

III. Explanation

Within their groups again, students should hypothesize why the mass of the ball is too large. Students should be clear that the density calculated should also apply to the larger ball.

Each group should record their ideas on a posterboard, whiteboard or large sheet of construction paper.

Day 2:

Share the posters with the entire class.

Scientists predict the amount of mass in a galaxy two ways.

One is with the mass to light ratio for the galaxy, just like you predicted the mass of the foam ball.

The second way is to use Newtonian Gravitation and relate the speed of rotation to the mass of the galaxy. The observed redshift of the light from galaxies gives rotation speeds that are too fast to be explained by the quantity of matter we can see. In fact, the rotational velocities that are observed are faster than the escape velocities based on the amount of matter that is visible.

Explain that scientists have predicted that there is more mass in the universe than they can see. In fact it is a LOT more than we can actually see. Because it is not bright enough to see, scientists call this extra mass dark matter and are doing just what the students did. Astronomers are hypothesizing what that matter may be.

Allow students time to make suggestions as to what the dark matter is. This may be done as a think-pair-share or as a whole class discussion. Record ideas on the board so that students have them in front of them as they write their report to NASA. Reports can be made in any number of ways, depending on your class – reports written as though they are formal reports to the NASA upper management, cartoons, podcasts, posters, etc.

IV. Extension

Students can do further research to find out what some of the newest thoughts are about dark matter. Suggested types of dark matter are MACHOS and WIMPS.

V. Evaluation

The student will report on his/her findings and hypothesize what might be causing the higher speeds and what the "missing" matter might be. The report will be a one page report to the directors at NASA.